System-Wide Optimization of the NAS: Phase II Concept Self Assessment

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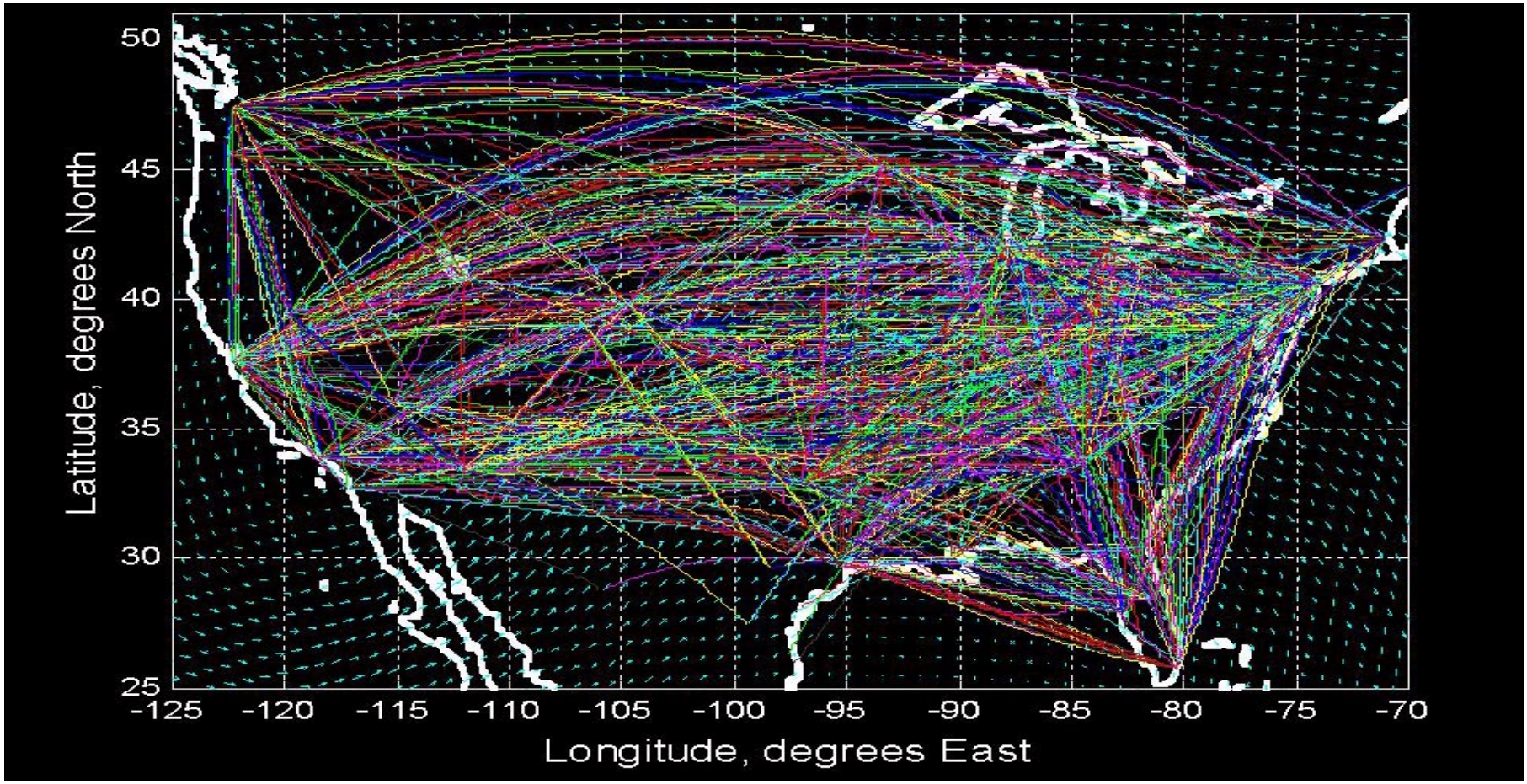
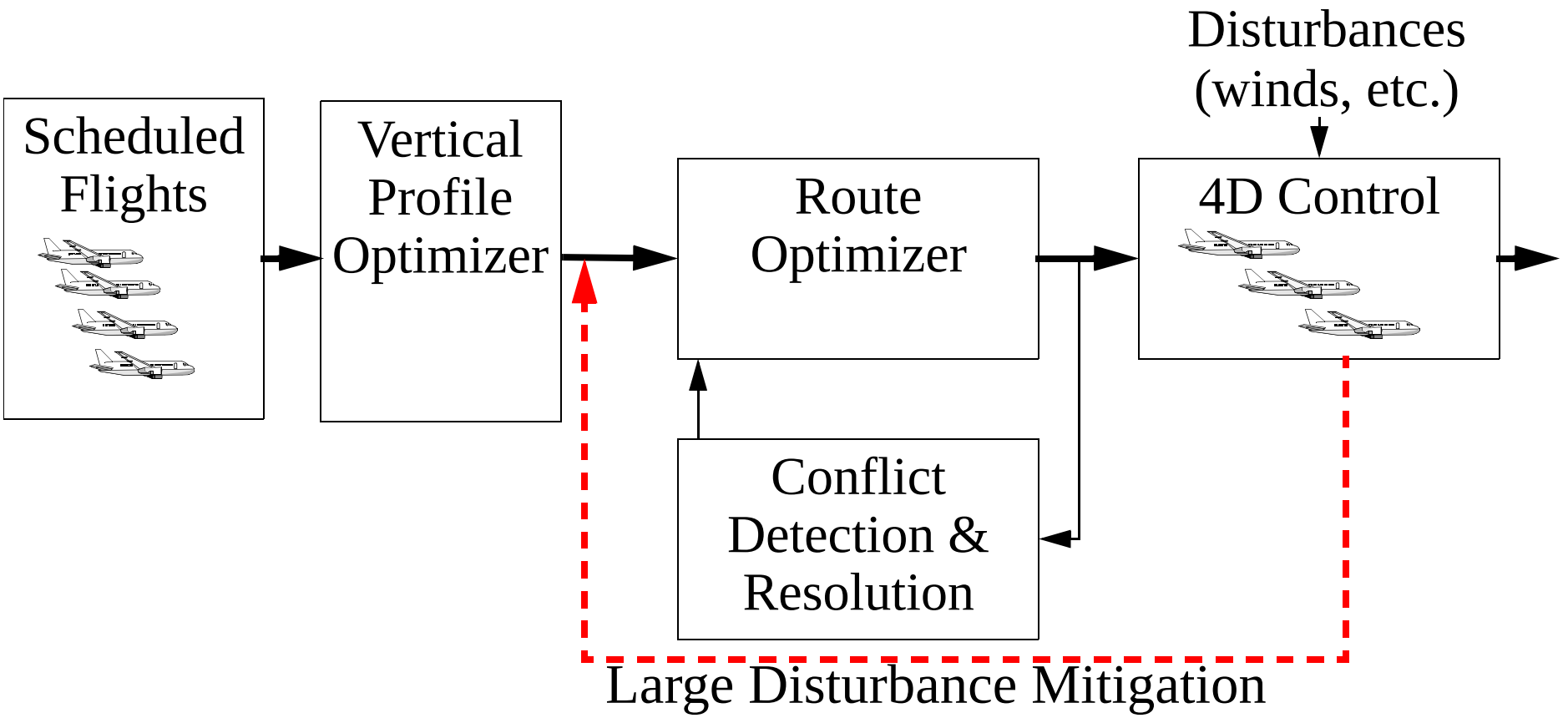
Background: System-Wide Optimization

Develop *Practical* Real-Time Method to Optimize and Deconflict Enroute Trajectories of All Aircraft on a Continental Scale



Background: System-Wide Optimization

- Strategic Optimization & Conflict Resolution
- 4D Guidance & Control
- Periodic Re-optimization & Conflict Resolution



Core Ideas

- Sequential Trajectory Optimization

  Optimize each trajectory, then hold fixed while optimizing following trajectories

- Neighboring Optimal Wind Routing (NOWR)

  NOWR is an efficient perturbation technique for optimizing trajectories in winds

- NOWR with Strategic Conflict Resolution (NOWR-CR)

  A modified form of NOWR which resolves conflicts in a near-wind-optimal manner

- Stochastic Conflict Grid (SCG)

  The SCG is an algorithm for estimating conflict probability over strategic time horizons

- Enhanced Flight Plans (EFP)

  The SWO concept will make use of 4D trajectories requiring enhanced flight plans

- Tactical Conflict Resolution

  Tactical conflict resolution is to be employed during execution of strategic plans as a backup

Anticipated Benefits

- Improved Fuel/Time Efficiency
  - Minimize fuel use for a given schedule
  - Reduce scheduled times through repeatable reduction in flight time
- Increased Enroute Capacity
  - Open all enroute airspace
  - Provide automation algorithms & tools for free routing operations
- Improved Strategic Situational Awareness
  - Reduce occurrence of tactical surprises
  - Enhance safety through stable trajectory planning

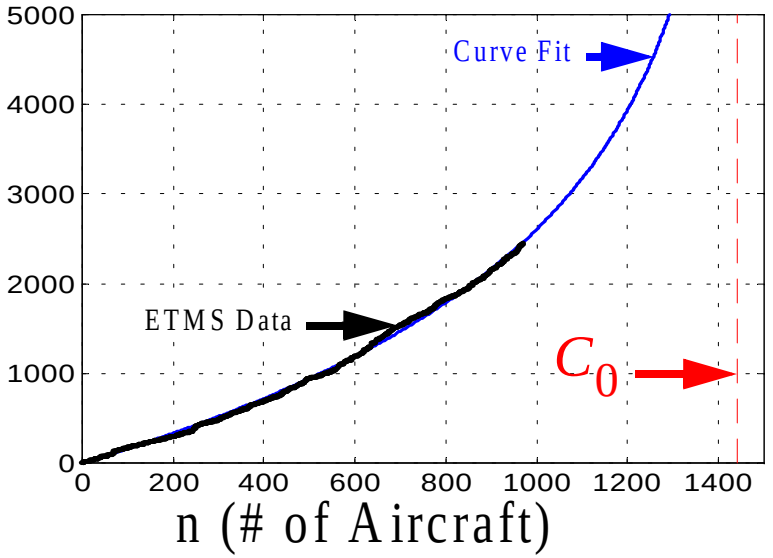
Metrics

- Flight Time Efficiency Parameter

$$\eta_{FT} \equiv \frac{\sum_{i=1}^{N_{AC}} (\text{Optimum Flight Time})_i}{\sum_{i=1}^{N_{AC}} (\text{Actual Flight Time})_i}$$

- Predicted Airspace Capacity

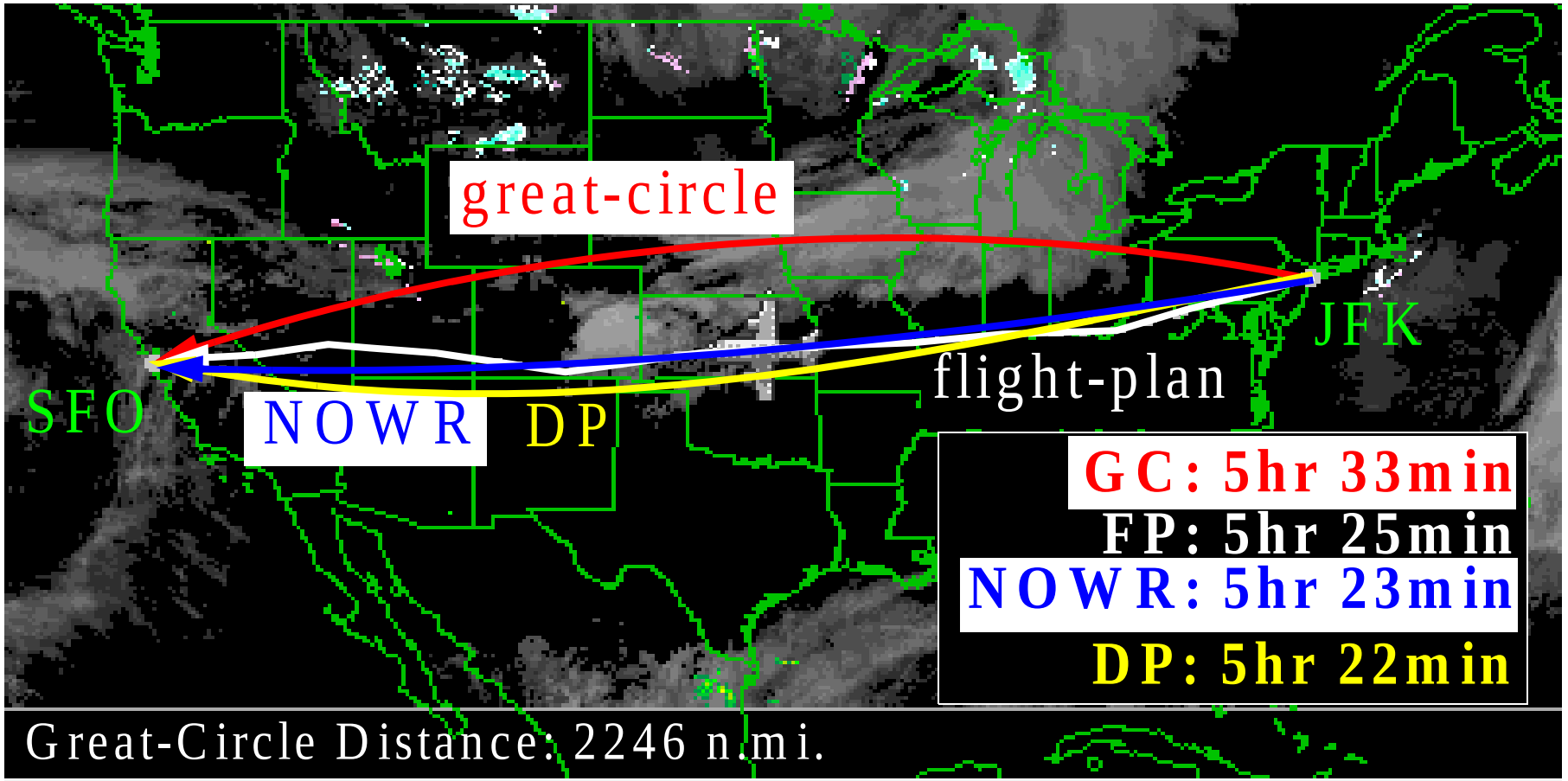
$$y_n = C_1 \ln\left(\frac{C_0}{C_0 - n}\right) \longrightarrow y_n$$



Self-Assessment Approach

- Begin with evaluation of core algorithms
- Evaluate fundamental performance of NOWR vs. benchmark optimization algorithm (Dynamic Programming)
- Evaluate performance of NOWR vs. great circle routes
- Evaluate performance of NOWR vs. filed flight plans
- Evaluate computational efficiency of NOWR

NOWR Comparisons



FLIGHT: UNITED AIRLINES 15 (B744)
DEPARTING: KENNEDY
ARRIVING: SAN FRANCISCO
DEPARTURE TIME 12:22 P.M. PST **February 11, 2002**
EXPECTED TO ARRIVE IN 2 HRS 46 MIN (5:47 P.M. PST)
SPEED: 441 Knots, ALTITUDE: 39000 Feet

Flight-plan image courtesy of:
http://www.flightprogress.com/

Self-Assessment Data & Analysis

- Identify common routes and weather data files for analysis
- Compute normalized flight-time differences between NOWR and great-circle or dynamic programming routes

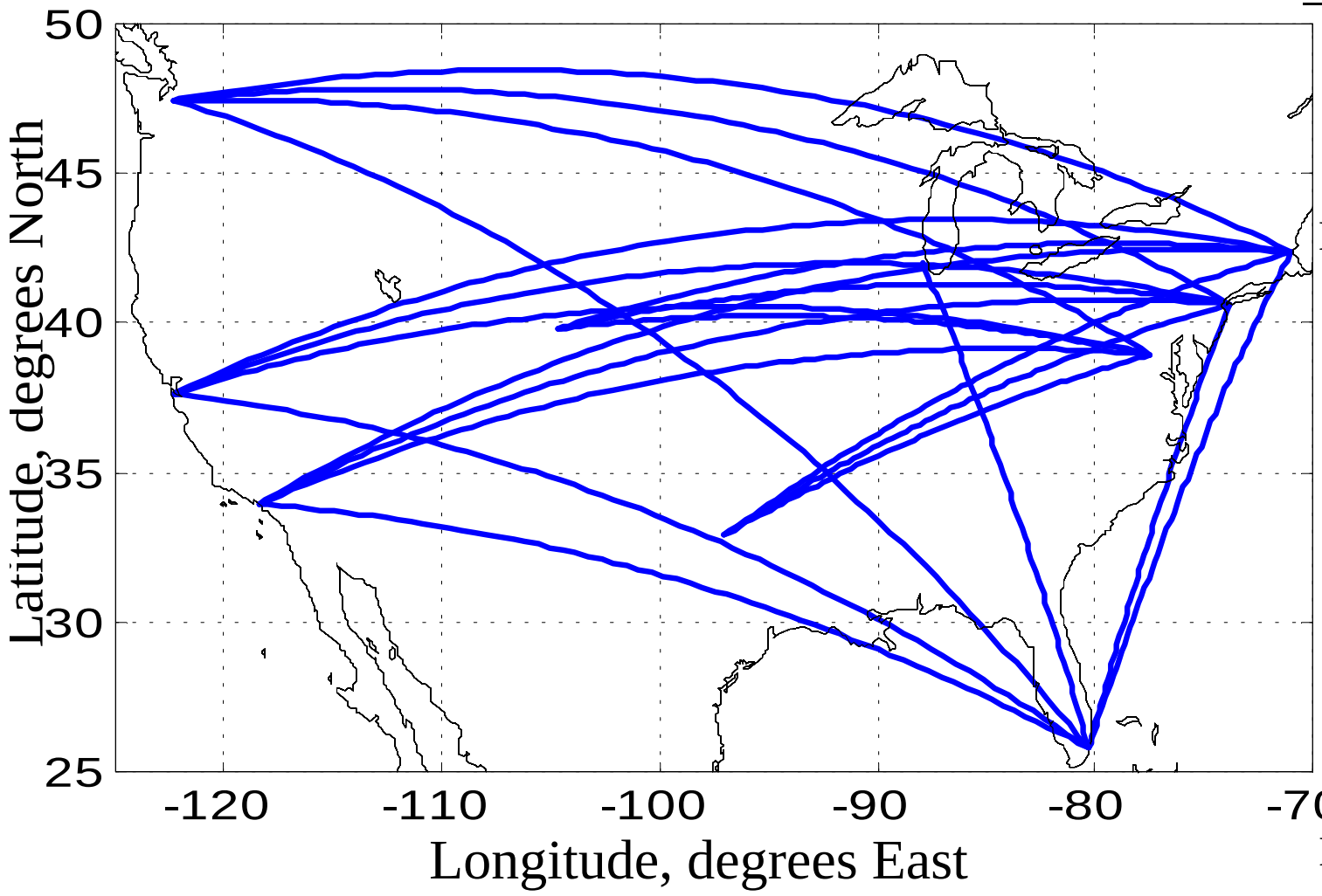
$$\Delta\tau = \frac{T_{\text{gc/dp}} - T_{\text{nowr}}}{T_{\text{dp}}}$$

- Compute confidence intervals

$$I_c = z_c \sqrt{\frac{\hat{S}^2_{\text{nowr}}}{n} + \frac{\hat{S}^2_{\text{gc/dp}}}{n}}$$

- Adjust number of simulation runs, n, until confidence intervals are within desired range: $\bar{\Delta\tau} \pm I_c$

Self-Assessment Data & Analysis



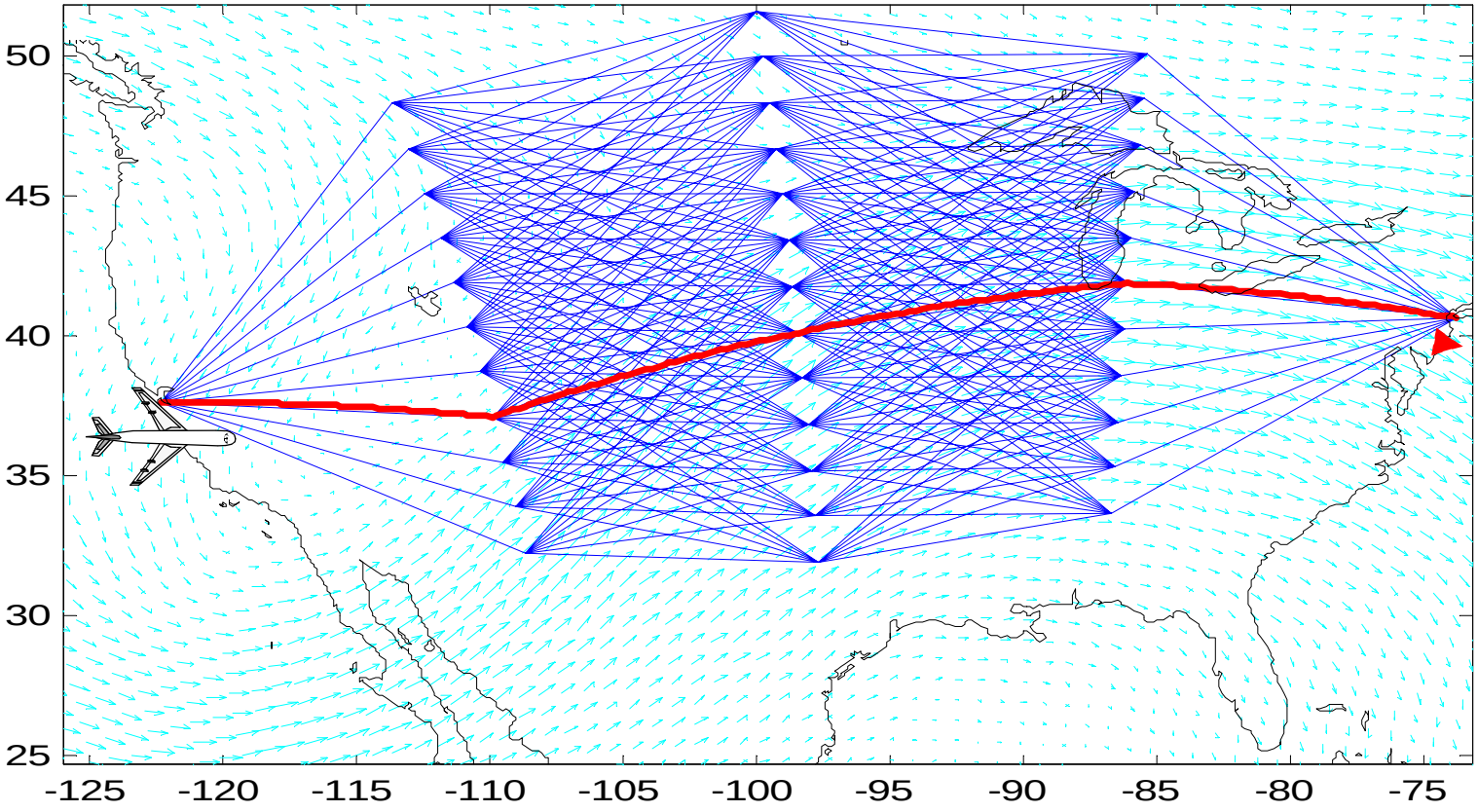
ROUTES

- JFK, BOS } to & from { SFO, SEA, LAX, DFW, DEN, MIA
- IAD } to & from { SFO, SEA, LAX, DFW, DEN
- MIA } to & from { SFO, SEA, LAX, ORD

Self-Assessment Data & Analysis

Date (UTC)	Filename	Description
2/14/2001	ruc2.T21Z.grb2f02	• RUC version 2 file • Vertical Coordinate: pressure level, millibars • GRIB Spec: Grid 211 (80 km & 25 mbar resolution) • Analysis time: 2100 universal coordinated time (UTC) • Altitude: Constant at 225 mbar pressure level (36,000 ft)
2/11/2002	ruc2.T19Z.grb2f02	• Analysis time: 1900 UTC (other parameters same as previous)
2/12/2002	ruc2.T19Z.grb2f02	(same as previous)
2/13/2002	ruc2.T07Z.grb2f02	• Analysis time: 0700 UTC (other parameters same as previous)
2/14/2002	ruc2.T19Z.grb2f02	• Analysis time: 1900 UTC (other parameters same as previous)
2/20/2002	ruc2.T21Z.grb2f02	• Analysis time: 2100 UTC (other parameters same as previous)

Neighboring Optimal Wind Routing: Performance Evaluation



- Discrete Dynamic Programming Search
- Adjust Grid Density until Solution Converges to Optimum

NOWR vs. DP & Great Circle Routes

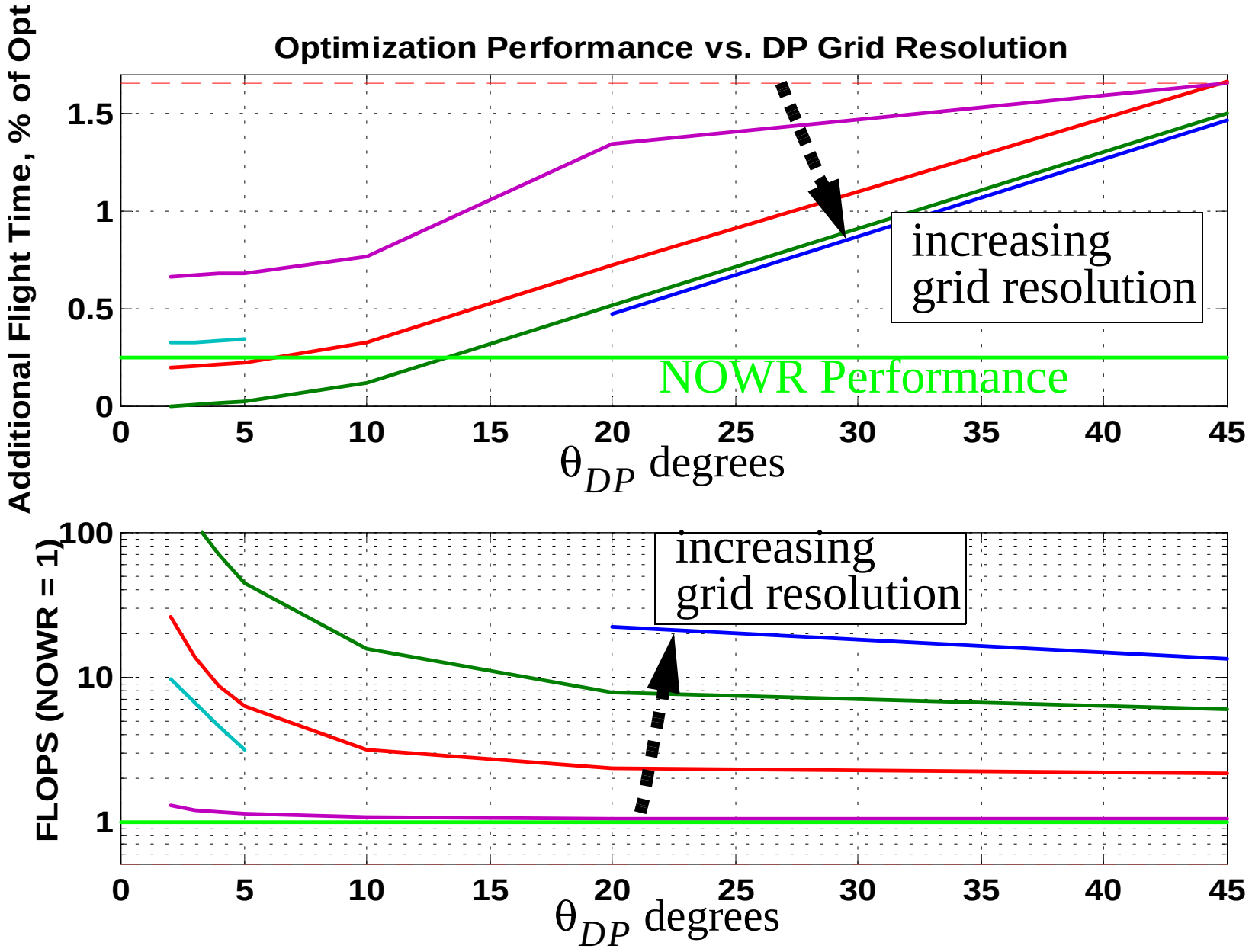
Dynamic Programming Solution Comparisons

- 6 Wind conditions, 42 Cross-Country Routes: 252 Simulations
- Compute Floating Point Operations & Total Flight Time
- Vary DP Grid Resolutions
- Compare DP Solutions to great-circle and NOWR Solutions

Results

- 7 milliseconds per NOWR computation (hp Itanium-2)
- $\Delta\bar{\tau}_{nowr\_dp} = 0.3\% \pm 0.12\%$
- $\Delta\bar{\tau}_{nowr\_gc} = -1.4\% \pm 0.26\%$
- NOWR solution within 0.3% of true optimum, on average
- NOWR solution better than great-circle by 1.4%, on average

NOWR vs. DP & Great-Circle Routes

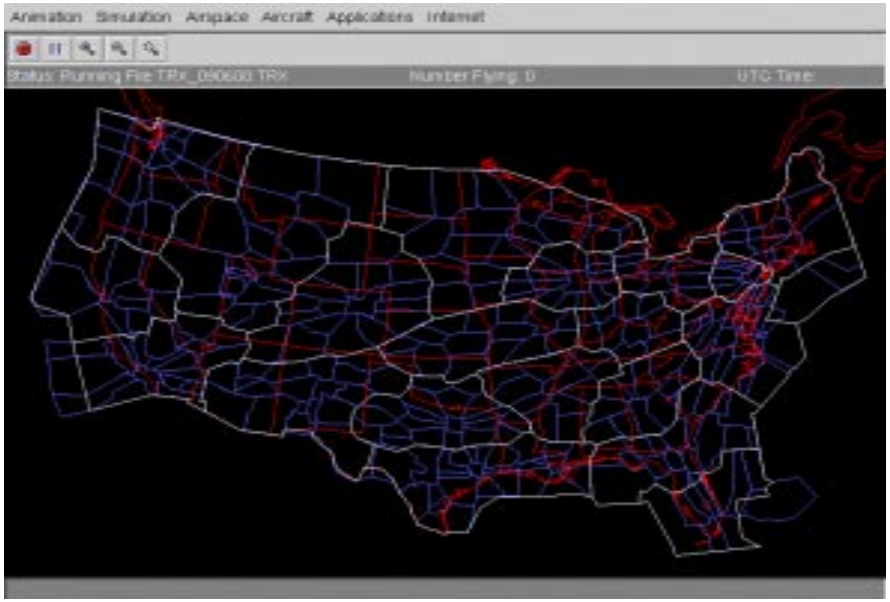


FACET Simulation Analysis

[Show Animation]

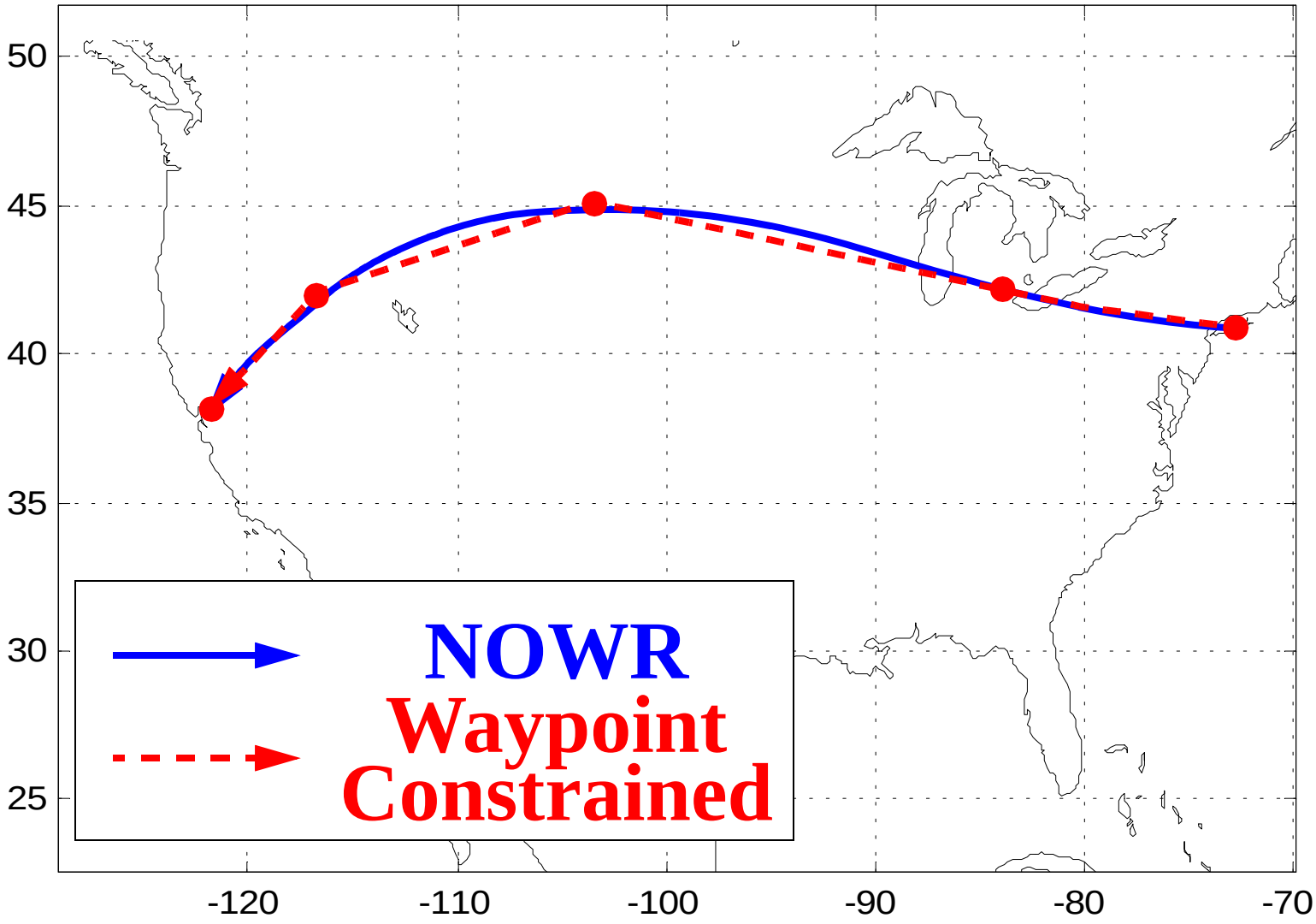
NOWR vs. Filed Flight Plans

- FACET Simulations (on-going)
- ETMS data from 00:00 UTC 2/12/02 to 00:00 UTC 2/13/02
- Utilize corresponding RUC data (high wind shear data)
- Traffic from FL330 & FL350 combined (> 4000 aircraft)
- Integrate along filed flight plans and NOWR routes

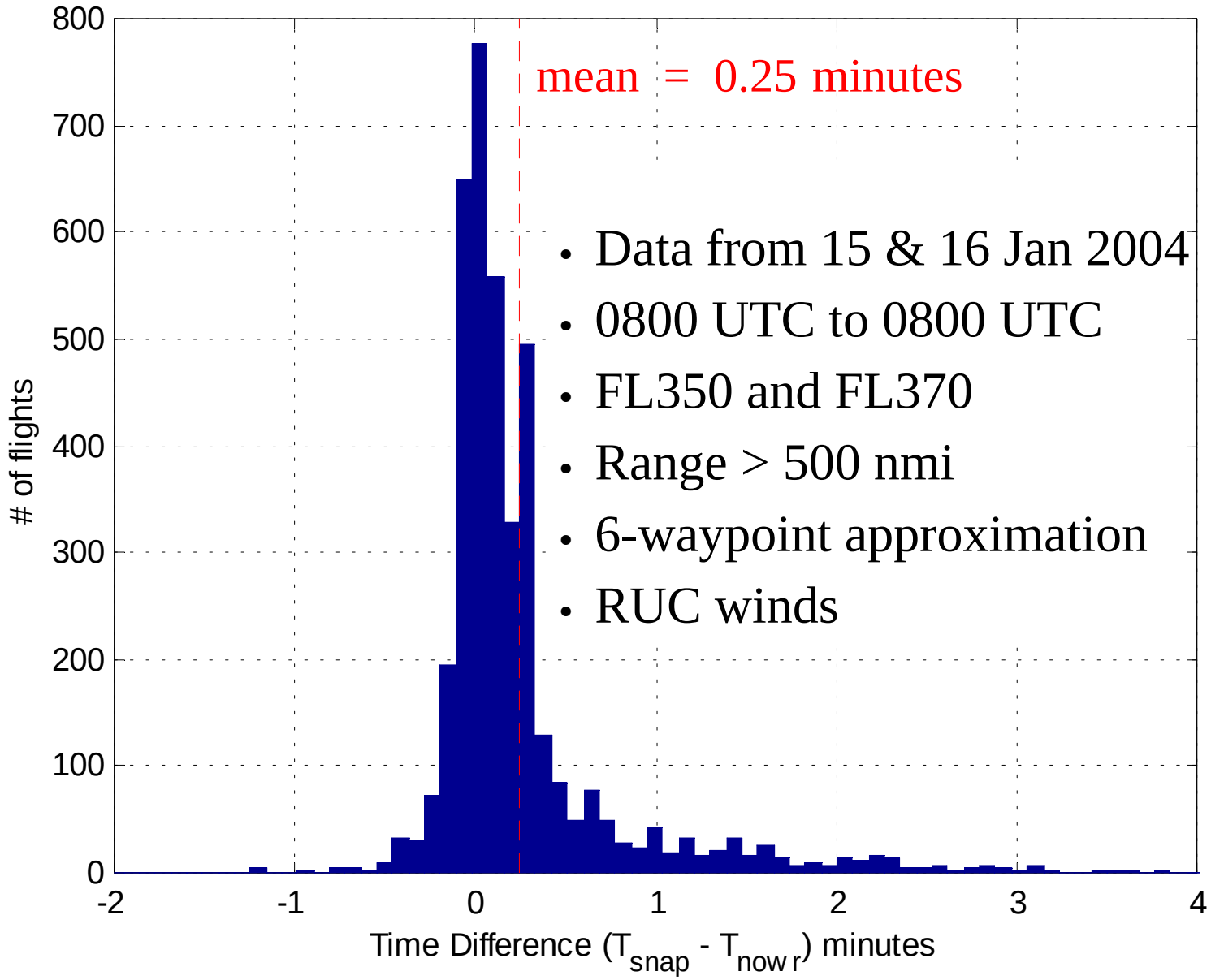


- Total time savings: 243 hr.
- Represents 4.5% improvement
- ~ $0.5M per day

NOWR vs. Waypoint-Constrained NOWR



Preliminary Results: $T_{SNAP} - T_{NOWR}$



Lessons Learned

- Optimal wind routing is beneficial: Full results coming soon.
- NOWR is an efficient algorithm for optimal routing
- Waypoint-constrained NOWR is still beneficial
- Enhancements are needed to make NOWR more practical
  - NOWR with constrained arrival time
  - NOWR in 3 dimensions
- Time to begin evaluating conflict detection/resolution
  - Stochastic Conflict Grid
  - NOWR with Conflict Resolution

Challenges

- Enhancements to NOWR algorithm not trivial
  - Add vertical profile optimization to NOWR
  - Add arrival-time constraint to NOWR
- Must still port Stochastic Conflict Grid to C-language
- Conflict resolution with snap-to routes requires different algorithm than NOWR-CR.